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The YF-12 Flight Research Program

Two YF-12s, forerunners of the famed SR-71 Blackbird reconnaissance aircraft, were flown in a joint NASA-Air Force research program from 1969 to 1978 to study the thermal, structural, and aerodynamic effects of sustained flight on airframes at speeds of Mach 3 -- three times the speed of sound -- at altitudes above 80,000 feet.

The extremely successful program, based at the NASA Dryden Flight Research Center, Edwards, Calif., used the YF-12s as test beds for studies and experiments that have contributed to the advancement of aeronautics in many disciplines -- propulsion technology, structures, aerodynamics, thermodynamics, instrumentation, and human factors.

The YF-12s were one of several models in the Blackbird family of aircraft built by Lockheed. Developed as prototypes of fighter-interceptor versions of the A-12, the YF-12s evolved into the SR-71 reconnaissance aircraft, which became the world's fastest and highest-flying production aircraft -- a distinction they still claim.

NASA's involvement in supersonic research dates to the pre- and post-World War II days of its predecessor agency, the National Advisory Committee on Aeronautics (NACA). Once the Bell X-1 became the first aircraft to fly supersonic in 1947, in a joint NACA-Air Force program, the agency's supersonic database was filled fast over the next 20 years by an assortment of research and X-series aircraft. By 1967, the X-15 had reached a speed of 4,520 mph (Mach 6.7), still the fastest of any winged aircraft.



The unique planform of a YF-12 flown in the joint NASA-Air Force program can easily be seen in this overhead view of aircraft No. 60-6935. The triple-sonic aircraft were excellent platforms for aerodynamic and thermal research.

NASA Photo E-23131

But as successful as the "X" planes were in their individual research programs, the flights were very short in duration. They produced data in many areas, but NASA engineers -- not only at Dryden but also throughout the agency -- were still seeking more information on sustained flight in a true supersonic cruise environment. The data would be used to help develop advanced supersonic and hypersonic aircraft.

The NASA-Air Force YF-12 research program was publicly announced in July 1969 and flying commenced the following December. Except for down time due to maintenance and modification work, one of the two YF-12s flew nearly every week for most of the program's nine-year lifetime. The program ended Oct. 31, 1979, with 297 flights logged and 450 flight hours accumulated.

Setting the Program Stage

NASA engineers and researchers say the true significance of the YF-12 research program is measured -- and hidden -- in its influence on the design, development, and performance of current and future aircraft.

The program was initially structured to analyze the original Air Force-Lockheed Blackbird test program to better understand high-altitude supersonic handling qualities, structural integrity, propulsion systems, and the relationship between aerodynamics and propulsion systems. The NASA-Air Force program later expanded to include experiments unrelated to the YF-12 such as upper atmospheric physics, human factors, and engine pollution studies.

The Air Force flight test program on the YF-12 ended in 1966. Even though SR-71s were becoming operational then, military officials lacked technical data in several areas of its operational environment and accepted a proposal to take part in

a formal research effort with NASA. One of the immediate beneficiaries of the program were the SR-71s, which received improvements in engine efficiency, stability, and control that grew out of the research efforts.

At the time the research program was being formulated, several American aerospace companies were developing plans for a supersonic transport (SST). NASA was then looking at the YF-12s as an important source of supersonic cruise data that would contribute to the SST's development. Although SST work was stopped in 1971, YF-12 research data applicable to the design and development of a high-speed transport are still useful -- and available -- today.

During the program's lifetime, engineers and researchers, covering nearly all areas of the program's research and experimentation, published over 125 scientific reports. Research results were also presented in several symposiums attended by hundreds of aerospace and military representatives. They acknowledged that the YF-12 program produced a wealth of information and would contribute to the advancement of American aeronautical capabilities.

Thermodynamics Research

One of the major areas of research in the YF-12 program was thermodynamics -- the study of heat generated by high-speed and what effects it has on aircraft structures and performance. A major goal of the study was to learn how much of the airframe loading in flight stemmed from thermal heating, and how much was the result of flight dynamics.

As the YF-12s cruised at speeds of more than 2,000 mph, friction with the atmosphere produced structural and skin temperatures of more than 1,000 degrees (F) in some areas, and the thermal heating and stresses changed the shape of the airframe. At

these speeds, aerodynamic loads are also applied to the airframe and can change the shape of structures and components. Separating aerodynamic and thermal forces gave engineers and designers additional tools to make future aircraft structurally stronger and safer.

Dryden engineers placed an entire YF-12 airframe in the Center's where it was heated to temperatures representing a speed of Mach 3. The heating system consisted of 16,430 quartz lamps mounted on metallic reflectors contoured to match the aircraft shape. The system, covering a 5,000 square-foot area, had 470 independently controlled zones enclosing the upper and lower surfaces of the airframe. Each zone had individual temperature and time controls linked to a central computer to duplicate flight conditions that would be encountered by that zone in actual flight.



Heat lamps tailored to the shape of the YF-12's forward fuselage are tested in the Dryden Thermal Loads Facility prior to thermal and flight loading tests on the actual aircraft.

NASA Photo ECN 2788

The work in the Thermal Loads Facility gave researchers data on induced thermal stresses and what effects heat alone had on the structure. This information was then compared to in-flight heating and loads data recorded on an instrumented YF-12. The correlation between flight tests and laboratory

tests produced instrumentation and test procedures that could be applied to future aircraft and vehicles being subjected to high in-flight temperatures. The tests also gave aircraft designers timely information on heat transfer and its potential impact on structural integrity.

Thermal testing also gave Lockheed engineers data relating directly to the Blackbird aircraft because the calibrated data allowed them to correct their own high-Mach loads data for adverse thermal effects.

Another significant spinoff of the thermal heating studies was the development by NASA of instrumentation, unavailable then, that could withstand the high temperatures generated by aerodynamic heating.

Propulsion Studies

The YF-12 program furnished a significant amount of propulsion data for future use, and -- similar to the thermal loads tests -- allowed engineers at that time to validate then-current predictions and wind tunnel test techniques. The research also led to major system improvements to the operational SR-71 fleet.

Two Pratt and Whitney J58 engines with mixed compression inlets powered the aircraft. At higher speeds, where the aircraft flew with greatest efficiency, air entering the inlets was supersonic and slowed to subsonic before reaching the first components of the engines. The flow of air was controlled by a moveable cone (spike) that positioned the standing shockwave, and forward bypass doors that also helped position the shockwave and allowed a certain percentage of air to bleed off from the inlet. If airflow was not properly matched to the inlet by the cone and bypass doors, the shockwave created drag.

Early in the program, researchers quickly saw that the dynamics of the engine inlets had a negative

effect on the stability and control of the aircraft. It was also known that inlet behavior was a problem for Lockheed during aircraft development.

Working with representatives of the engine manufacturer and Lockheed, Dryden researchers developed a computer model of the engine and inlet system. Scaled and full-size inlet models were then tested in wind tunnels. Computer and wind tunnel data were compared with flight data and the correlation between these sources produced useful test and prediction techniques.

The studies allowed researchers to understand engine "unstarts" associated with all Blackbirds. An "unstart" occurs when the flow of air into the inlet is not properly matched to the engine and causes the standing shockwave to be expelled out the front of the inlet, resulting in insufficient pressure and air for normal engine operations. This created a sudden loss of thrust and a power imbalance that caused violent yawing, along with pitching and rolling motions. Crewmembers unfamiliar with "unstarts" often thought the aircraft would break up.

The "unstart" studies led to development of an automatic inlet sensing and cone control system that significantly reduced the frequency of "unstarts."

The studies also revealed that strong vortices rolled off each of the forward fuselage chines and passed directly into the inlets. This information helped determine the percentage of air passing through the engines and the percentage leaving the inlet through the forward bypass doors. A computer control system for the bypass doors was developed that hiked engine efficiency and helped increase the range and performance of the operational SR-71 fleet.

The Cold Wall Experiment

The YF-12 was an excellent platform for researchers studying high-temperature phenomena unassociated with the aircraft itself. The most

prominent was called the Cold Wall Experiment. The experiment was successfully carried out just once, but the test and its findings are considered very significant by researchers in the fluid dynamics field.

The Cold Wall device was a large stainless steel cylinder chilled with liquid nitrogen and instrumented with thermocouples and sensors. An extremely efficient insulation containing an explosive primer cord was then wrapped around the cylinder, which was mounted on a pylon beneath the fuselage just forward of the engines.

As the aircraft neared a speed of Mach 3, the primer cord blew the insulation away from the frigid tube, exposing it instantly to a high-temperature, high-pressure environment. Thermal and air pressure data collected by the instrumentation system produced readings that were compared with data from theoretical analysis and wind tunnel tests, and added greatly to the fluid dynamics scientific data base.

Improving Supersonic Cruise

Researchers used a YF-12 as a tool to study handling characteristics at supersonic cruise speeds. NASA researchers needed to know more about holding a high-speed aircraft at a desired cruise



YF-12s in formation flight at dusk. The aircraft in the foreground carries the insulated cylinder used in the Cold Wall Experiment on a pylon mounted beneath the fuselage.

NASA Photo ECN 4767

altitude. Out of this research came the development of the Cooperative Airframe-Propulsion Control System (CAPCS), a digital computer system that incorporates data from many sources to produce what has been called a "technological breakthrough in flight path control for supersonic aircraft."

CAPCS was ultimately incorporated on operational SR-71s. Now, decades later, the research data used to develop CAPCS are still used by engineers and designers improving high-speed aircraft handling qualities.

Most all aircraft being flown by an autopilot system tend to settle into a natural pitching motion (oscillation) that can result in major altitude deviations. Such oscillations, called phugoids, were common with the YF-12s, and with the automatic engine inlet systems, the porpoising movements could become unstable. At supersonic speeds, even the slightest deviation from the desired flight path can quickly result in differences of thousands of feet. The YF-12s also experienced deviations in speed and altitude that were triggered by quick temperature and pressure changes associated with sudden acceleration.

Researchers developed a CAPCS to integrate control of the aircraft's engine inlets, autopilot, autothrottle, air data collection system, and the navigation system. Flight tests exceeded the goals of the researchers and design engineers by improving flight path control precision by a factor of 10. The system also improved the aircraft's range by seven percent, inlet unstarts were almost totally eliminated, and CAPCS was ultimately installed on operational SR-71 aircraft.

Much of the research that produced CAPCS was also intended to benefit development of a future American supersonic transport. That database still exists to be used in the development of any future high-speed aircraft in the United States.

In-Flight Diagnostics

NASA developed the precursor of in-flight diagnostic checkout systems used on aircraft today for the YF-12 program.

The system was called a Central Airborne Performance Analyzer (CAPA). It monitored many parameters associated with the aircraft's electrical and inlet control systems, along with the hydraulic system.

If a problem occurred during flight, a CAPA readout was displayed on a cockpit monitor for the pilot, including a recommendation if the flight was serious enough to be aborted.

After each flight, maintenance personnel used data displayed by the system to determine what types of maintenance, beyond normal procedures, were required before the aircraft could be flown again.

A maintenance diagnostic system is now built into nearly every new U.S. military aircraft, many commercial aircraft, and also the Space Shuttles. They alert crewmembers of system problems during flight, while also giving maintenance technicians a post-flight list of servicing and replacement needs.

The Flying Laboratory

Many experiments unrelated to the Blackbird family of aircraft were conducted with the YF-12s. These flights, in which the aircraft were used as airborne testbeds and wind tunnels, contributed significantly in many scientific and aerospace disciplines.

Engineers at Dryden used the aircraft to help the Langley Research Center evaluate advanced lightweight aircraft structural panels. Each of the

test articles was placed on the aircraft and subjected to many hours of high-speed flight, enduring high temperatures and dynamic air pressures. Measuring about 16 by 28 inches, the panels were examples of weld brazed titanium skin stringer panels, a titanium honeycomb core sandwich panel, and a sandwich panel of titanium honeycomb with a boron-aluminum face sheet. All exceeded the test requirements and are examples of today's aircraft structural technology.

The capability of flying at 80,000 feet -- above most of the earth's atmosphere -- gave NASA researchers the chance of documenting upper atmosphere physics and dynamics. Atmospheric models were then produced that are still being used for weather predictions, and by designers of future piloted and unpiloted high-altitude research aircraft.

Researchers used the aircraft for extensive studies of the boundary layer, the often-turbulent layer of air flowing across an aircraft's surface that produces drag and reduces flying efficiency. Engineers typically use theories to predict the boundary layer behavior of new aircraft designs, but these theories often produce values that differ drastically from flight and wind tunnel data. Instruments called boundary layer rakes were attached to the YF-12 aircraft to collect data at different points in the air stream. The flight data were compared with ground tests, and discrepancies between the two were used to update engineering theories.

The YF-12 program also contributed to the study of human factors in a high-altitude, supersonic cruise environment. Using the actions of crewmembers during the flights, researchers identified and studied many workload tasks. Data were then compared with the results of clinical studies to develop a pilot workload model from which predictions could be made. The model continues to be useful to engineers and designers

developing more efficient cockpits and aircraft systems on new high-altitude, high-speed aircraft.

A series of YF-12 low lift-over-drag landing demonstrations in the Spring of 1973 helped NASA's space shuttle planning and development team understand the probable landing dynamics of the shuttle vehicles. A series of 26 steep landing approaches were flown with a YF-12 in a high-drag configuration. The flights gave engineers very useful data for low lift-over-drag ratios of 2 to 3, the expected ratio of the space shuttle vehicles then being developed.

A study of the landing and taxi characteristics of the YF-12 produced a mixed-volume dual-mode gear system that reduced aircraft dynamic response during high-speed taxi runs and produced a smoother ride for the airframe over varying runway conditions. The concept was incorporated into the SR-71 aircraft fleet, while analytical results from a digital computer program provided excellent correlation with operational test data.

Other research conducted with the aircraft included studies of jet wake dispersion, and the effect of a boattail aircraft design on aerodynamic drag.

Aircraft History

The family of aircraft commonly referred to as the Blackbirds includes the A-12, YF-12, and the SR-71: all developed by the Advanced Development Projects office of the Lockheed Corporation -- a corporate branch known as the Skunk Works.

The initial design was for the A-12, a supersonic successor to the U-2 reconnaissance aircraft. The A-12 was capable of reaching a speed of Mach 3.29 and an altitude of 90,000 feet. It was flown exclusively by the Central Intelligence Agency (CIA), which approved construction funding in

August 1959. The A-12 fleet operated in secrecy until June 1968, when the aircraft remaining at that time were placed in storage at Air Force Plant 42, Palmdale.

Before delivery of the first A-12, Lockheed and the Air Force discussed development of a fighter-interceptor version of aircraft. The prototypes of that model were designated the YF-12A. The first aircraft carried a tail number of 60-6934 and its maiden flight was in August 1963. Two more aircraft, No. 60-6935 and 60-6936, were built and flight-testing continued through 1963 and into 1964.

In 1964, after YF-12 testing had shifted to Edwards AFB, the aircraft established several official speed and altitude records. That same year, the Air Force and Lockheed announced development of a long-range strategic reconnaissance aircraft. That aircraft was a modified version of the YF-12 and designated the SR-71 and plans for the fighter-interceptor model were dropped.

The NASA-Air Force YF-12 research program began with aircraft 60-6935 and 60-6936. In 1971, an in-flight fuel line failure on No. "936" led to an engine fire during a landing approach at Edwards AFB. The two crewmen ejected safely, but the aircraft was destroyed in a fiery crash on the northern edge of the base. The aircraft was replaced in the program by a still-secret SR-71A that was modified with YF-12 engines and inlets. The aircraft was then given a bogus tail number of 60-6937 and was called a YF-12C. The main difference in appearance between "937" and the YF-12s were the fuselage chines which extended to the tip of the nose. Fuselage chines on YF-12s ended before reaching the nose cone.

Blackbird Specifications

The Blackbird family of aircraft was built primarily from titanium alloy, which enabled them to withstand skin temperatures of over 1,000 degrees (F) while flying three times the speed of sound.

All three aircraft flown in the NASA-Air Force research program had two-seat cockpits: a pilot station and a rear seat used by the flight engineers. On operational Air Force aircraft, systems operators occupied the rear seat.

Wingspan: 55 ft., 6 in

Length: 101 ft., 8 in

Height 18 ft., 4 in

Maximum loaded weight: 127,000 lbs

Range: More than 2,000 miles, with aerial refueling capability

Speed: Mach 3.2 -- more than three times the speed of sound

Service ceiling: Above 80,000 ft

Engines: Two Pratt & Whitney J-58 turbo-ramjets rated at 32,000 lbs thrust with afterburners. As the aircraft neared Mach 3 speeds a significant portion of the thrust was produced from the supersonic shockwave captured within each engine inlet and exited through the engine nozzles.